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COMPARISON OF FLAME PHOTOMETER DATA WITH TOTAL PARTICLE  
VOLUME CALCULATED.. (U) SCHOOL OF AEROSPACE MEDICINE  
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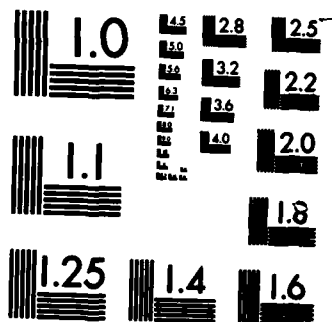
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# COMPARISON OF FLAME PHOTOMETER DATA WITH TOTAL PARTICLE VOLUME CALCULATED FROM LASER SPECTROMETER PARTICLE COUNT DATA

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December 1984

Final Report for Period 1 January 1984 - 30 June 1984

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The Office of Public Affairs has reviewed this report and it is releasable to the National Technical Information Service, where it will be available to the general public, including foreign nationals.

This report has been reviewed and is approved for publication.

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SECURITY CLASSIFICATION OF THIS PAGE

## REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION <b>UNCLASSIFIED</b>		1b. RESTRICTIVE MARKINGS	
2a. SECURITY CLASSIFICATION AUTHORITY		3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited.	
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE		5. MONITORING ORGANIZATION REPORT NUMBER(S)	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) <b>USAFSAM-TR-84-50</b>		7a. NAME OF MONITORING ORGANIZATION	
6a. NAME OF PERFORMING ORGANIZATION <b>USAF School of Aerospace Medicine</b>	6b. OFFICE SYMBOL (If applicable) <b>USAFSAM/VNC</b>	7b. ADDRESS (City, State and ZIP Code)	
6c. ADDRESS (City, State and ZIP Code) <b>Aerospace Medical Division (AFSC) Brooks Air Force Base, Texas 78235-5000</b>		9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER	
8a. NAME OF FUNDING/SPONSORING ORGANIZATION <b>USAF School of Aerospace Medicine</b>	8b. OFFICE SYMBOL (If applicable) <b>USAFSAM/VNC</b>	10. SOURCE OF FUNDING NOS.	
8c. ADDRESS (City, State and ZIP Code) <b>Aerospace Medical Division (AFSC) Brooks Air Force Base, Texas 78235-5000</b>		PROGRAM ELEMENT NO. <b>62202F</b>	PROJECT NO. <b>2729</b>
		TASK NO. <b>03</b>	WORK UNIT NO. <b>05</b>
11. TITLE (Include Security Classification) <b>COMPARISON OF FLAME PHOTOMETER DATA WITH TOTAL PARTICLE VOLUME CALCULATED FROM LASER SPECTROMETER PARTICLE COUNT DATA</b>			
12. PERSONAL AUTHOR(S) <b>Laird, A. Rachel; Beland, Daniel G.; and Goldberg, Irwin S.</b>			
13a. TYPE OF REPORT <b>Final</b>	13b. TIME COVERED <b>FROM 1/1/84/ TO 6/30/84</b>	14. DATE OF REPORT (Yr., Mo., Day) <b>1984, December</b>	15. PAGE COUNT <b>14</b>
16. SUPPLEMENTARY NOTATION			
17. COSATI CODES		18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)	
FIELD	GROUP	SUB. GR.	
<b>06</b>	<b>11</b>	<b>Laser spectrometer, Aerosols,</b>	
<b>15</b>	<b>02</b>	<b>Flame photometer, Respirator Quantitative Fit Test,</b>	
		<b>Sodium chloride, RQFT.</b>	
19. ABSTRACT (Continue on reverse if necessary and identify by block number) <b>Respirator Quantitative Fit Test (RQFT) Flame Photometer data have been compared with total particle volume calculated from LAS-X laser spectrometer particle count data. Total volume data were calculated by the method developed by Goldberg and Laird (1). Results indicate that there is a linear relationship between flame photometer voltage and the logarithm of sodium chloride (NaCl) total particle volume over 3-4 decades in NaCl concentration. Results also indicate that flame photometer voltage is not strongly dependent on NaCl particle size. Total particle volume data can be used to calibrate the flame photometer over about 4 decades in NaCl concentrations. Originator Supplied Keywords include:</b>			
20. DISTRIBUTION/AVAILABILITY OF ABSTRACT <b>UNCLASSIFIED/UNLIMITED <input checked="" type="checkbox"/> SAME AS RPT. <input type="checkbox"/> DTIC USERS <input type="checkbox"/></b>		21. ABSTRACT SECURITY CLASSIFICATION <b>UNCLASSIFIED</b>	
22a. NAME OF RESPONSIBLE INDIVIDUAL <b>A. Rachel Laird, Ph.D.</b>		22b. TELEPHONE NUMBER (Include Area Code) <b>(512) 536-2921</b>	22c. OFFICE SYMBOL <b>USAFSAM/VNC</b>

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# COMPARISON OF FLAME PHOTOMETER DATA WITH TOTAL PARTICLE VOLUME CALCULATED FROM LASER SPECTROMETER PARTICLE COUNT DATA

## INTRODUCTION

Goldberg and Laird [1] have shown that total particle volume derived from the LAS-X laser spectrometer data (Particle Measuring Systems, Boulder, CO) could be compared with flame photometer mass data if the limitations of the instruments and methods are properly considered. In this comparison, normalized particle volume data are used as an independent method of calibrating the USAFSAM Respirator Quantitative Fit Test (RQFT) instrument flame photometer.

The LAS-X is an optical single-particle counting instrument with a maximum particle count rate of approximately 3000 particles per second. In this system, multichannel particle size distribution data are given in which the number of particles in successive size interval ranges is determined. In one sense, an optical single-particle counting instrument can be considered to be a primary standard, because response is determined only by the presence of a particle in the viewing volume; if there is no particle in the viewing volume, there is no response. Some ambiguity, however, is associated with assigning a particle to a particular diameter range since some of these ranges overlap [1]. It is assumed that the ambiguity in assigning particle size is constant over all measurements, so that normalized total volume will not be affected.

Voltage from the flame photometer is theoretically proportional to the logarithm of the mass of sodium chloride (NaCl) burned in its flame [3]. The NaCl RQFT flame photometer is normally calibrated over 6 decades of NaCl concentration using 6 serially-diluted NaCl solutions. This calibration method has been questioned, because the actual logarithmic response of the flame photometer may not be linear with respect to particle size, which decreases with decreasing NaCl solution strength [4].

It can be assumed [1] that the volume of the particles counted by the LAS-X is proportional to the cube of the diameter (spherical) or length (nonspherical). The total volume derived from particle count data is, therefore, proportional to the total mass of the particles, and the logarithm of total particle volume should be proportional to voltage. Results indicate that a linear relationship between the logarithm of the total particle volume and voltage exists over 3 or more decades of particle volume.

## METHODOLOGY

A schematic diagram of the experimental apparatus is shown in Figure 1. Sodium chloride is sampled from the test chamber by the flame photometer sampling pump. Sodium chloride is also drawn from the test chamber and routed through a diluter and an aging chamber; the LAS-X samples are collected from the aging chamber. The dilution ratio cannot be measured accurately enough to derive particle number concentrations. Thus, all volume data are normalized to the maximum value.

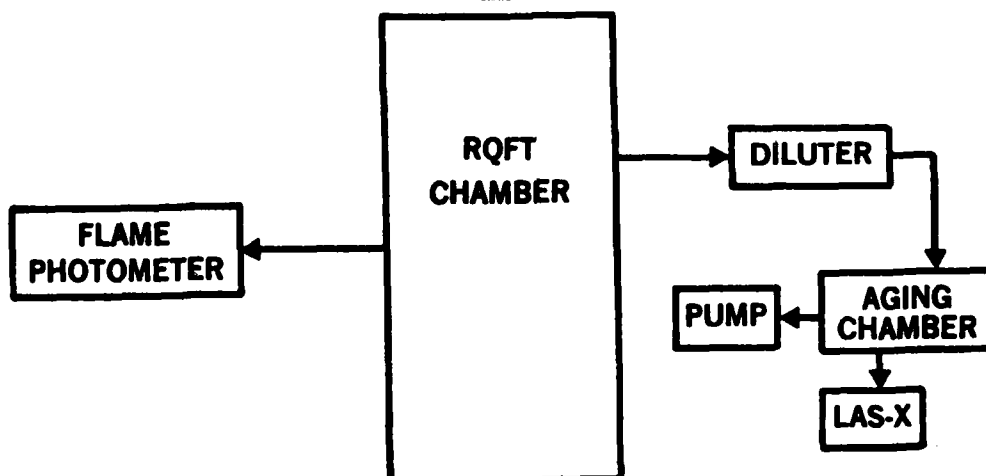


Figure 1. Schematic diagram of experimental apparatus

The NaCl aerosol is generated by a six-jet atomizer (TSI 9306). Operating conditions for three separate experiments are shown in Table 1; the fourth experiment is a replicate of the third.

TABLE 1. OPERATING CONDITIONS

NaCl solution*	Jets	Approximate dilution
Experiment 1		
1.0E-2	6	20:1
1.0E-1	6	20:1
1.0E-0	3	20:1
1.0E-0	6	20:1
Experiment 2		
1.0E-2	6	100:1
1.0E-1	6	100:1
1.0E-0	3	100:1
1.0E-0	6	100:1
Experiment 3		
1.0E-0	6	100:1
Experiment 4		
1.0E-0	6	100:1

\*  $10^{-2}$  is 0.05% solution,  $10^{-1}$  is 0.5% solution, and 1.0 is 5% solution.



In the first two experiments, NaCl concentration was varied by changing solution strength (from 5% to 0.05%) or by changing the number of jets in operation. (Concentration is directly proportional to the number of jets in operation.) In the third and fourth experiments, aerosol concentration was established using six jets and a 5% NaCl solution. The NaCl aerosol in the test chamber was then diluted by the addition of clean air over a period of 2-3 h, causing an approximately exponential decrease in chamber concentrations. It is assumed that particle coagulation, sedimentation, and losses to the walls are negligible. The major difference between Experiments 1 and 2, and Experiments 3 and 4 is that particle size distribution is variable in the first two and approximately constant in the last two experiments, due to variation or constancy in solution strength [3].

#### FLAME PHOTOMETER DATA

Calibration data obtained by Kolesar [3] is shown in Figure 2. The equation for the calibration curve as a function of voltage,  $v$ , is:

$$c = a_0 + a_1 e^v + a_2 (e^v)^2 + \dots + a_n (e^v)^n$$

where  $c$  is NaCl concentration and  $a_0, a_1, \dots, a_n$  are coefficients determined by a least-squares fit to the data. The nonlinearity and slope of the curve, particularly below  $1.0E-4$ , limit the confidence with which very low concentrations can be determined.

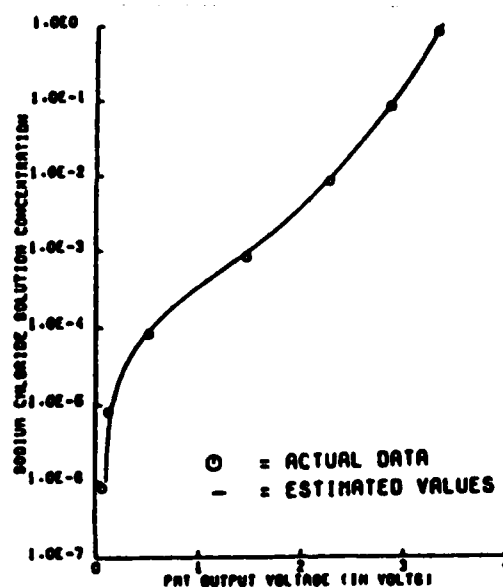


Figure 2. Calibration curve from Kolesar (3)

# LAS-X DATA

An example of aerosol volume calculated from LAS-X count data is shown in Table 2. Aerosol volume for each of 60 particle diameters is calculated as discussed by Goldberg and Laird [1]. The total particle volume for each of four size ranges and for all four size ranges are tabulated after size range 3. Because of the ambiguity of particle size caused by overlapping size ranges for the instrument, three estimates of volume are given. Thus, estimates of maximum, minimum, and average volumes are also shown. In this application, only the average estimate for total volume over four size ranges is used. In a separate calculation the count mean diameter (CMD) is determined, assuming a log-normal particle size distribution [2].

TABLE 2. LAS-X COMPUTER OUTPUT

DATA.001

DATE: 28-MAR-84  
TIME: 15:00:50

FLOW RATE (CC/SEC) = 5. RUN TIME (SEC) = 60.

\*\*\* RANGE = 0 \*\*\*

CH#	DIAM. (MICR)	#COUNTS	#CNTS/SEC	MIN VOL/S	MAX VOL/S	AVE VOL/S
1	1.500 - 1.900	839	1.3983E+01	2.4711E+01	5.0219E+01	3.5971E+01(S)
2	1.900 - 2.300	225	3.7500E+00	1.3468E+01	2.3890E+01	1.8184E+01(S)
3	2.300 - 2.700	77	1.2833E+00	8.1756E+00	1.3226E+01	1.0499E+01(S)
4	2.700 - 3.100	19	3.1667E-01	3.2636E+00	4.9395E+00	4.0438E+00(S)
5	3.100 - 3.500	5	8.3333E-02	1.2999E+00	1.8708E+00	1.5680E+00(S)
6	3.500 - 3.900	1	1.6667E-02	3.7415E-01	5.1766E-01	4.4203E-01(S)
7	3.900 - 4.300	1	1.6667E-02	5.1766E-01	6.9383E-01	6.0145E-01(S)
8	4.300 - 4.700	1	1.6667E-02	6.9383E-01	9.0603E-01	7.9522E-01(S)
9	4.700 - 5.100	0	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00(S)
10	5.100 - 5.500	0	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00(S)
11	5.500 - 5.900	0	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00(S)
12	5.900 - 6.300	0	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00(S)
13	6.300 - 6.700	0	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00(S)
14	6.700 - 7.100	0	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00(S)
15	7.100 - 7.500	0	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00(S)

\*\*\*RANGE= 0 SUBTOTAL: MIN ACCUM VOL/S = 52.503  
MAX ACCUM VOL/S = 96.263  
AVE ACCUM VOL/S = 72.105

\*\*\* RANGE = 1 \*\*\*

CH#	DIAM. (MICR)	#COUNTS	#CNTS/SEC	MIN VOL/S	MAX VOL/S	AVE VOL/S
1	0.300 - 0.400	275718	4.5953E+03	6.4964E+01	1.5399E+02	1.0316E+02(NS)
2	0.400 - 0.500	138104	2.3017E+03	7.7132E+01	1.5065E+02	1.0982E+02(NS)
3	0.500 - 0.600	35401	5.9002E+02	3.8616E+01	6.6729E+01	5.1399E+01(S)
4	0.600 - 0.700	15003	2.5005E+02	2.8280E+01	4.4908E+01	3.5955E+01(S)
5	0.700 - 0.800	8714	1.4523E+02	2.6083E+01	3.8935E+01	3.2081E+01(S)
6	0.800 - 0.900	5043	8.4050E+01	2.2532E+01	3.2082E+01	2.7027E+01(S)
7	0.900 - 1.000	3346	5.5767E+01	2.1286E+01	2.9199E+01	2.5035E+01(S)
8	1.000 - 1.100	2157	3.5950E+01	1.8823E+01	2.5054E+01	2.1790E+01(S)
9	1.100 - 1.200	1463	2.4383E+01	1.6993E+01	2.2062E+01	1.9417E+01(S)
10	1.200 - 1.300	954	1.5900E+01	1.4386E+01	1.8291E+01	1.6260E+01(S)
11	1.300 - 1.400	588	9.8000E+00	1.1273E+01	1.4080E+01	1.2625E+01(S)
12	1.400 - 1.500	444	7.4000E+00	1.0632E+01	1.3077E+01	1.1812E+01(S)
13	1.500 - 1.600	270	4.5000E+00	7.9522E+00	9.6510E+00	8.7742E+00(NS)
14	1.600 - 1.700	206	3.4333E+00	7.3633E+00	8.8320E+00	8.0754E+00(NS)
15	1.700 - 1.800	132	2.2000E+00	5.6594E+00	6.7180E+00	6.1736E+00(NS)

\*\*\*RANGE= 1 SUBTOTAL: MIN ACCUM VOL/S = 371.977  
MAX ACCUM VOL/S = 634.255  
AVE ACCUM VOL/S = 489.408

TABLE 2. LAS-X COMPUTER OUTPUT (Cont'd)

DATA.001

DATE: 28-MAR-84

TIME: 15:00:50

FLOW RATE (CC/SEC) = 5.

RUN TIME (SEC) = 60.

\*\*\* RANGE = 2 \*\*\*

CH#	DIAM.(MICR)	#COUNTS	#CNTS/SEC	MIN VOL/S	MAX VOL/S	AVE VOL/S
1	0.170 - 0.200	260891	4.3482E+03	1.1185E+01	1.8214E+01	1.4415E+01(NS)
2	0.200 - 0.230	211258	3.5210E+03	1.4749E+01	2.2431E+01	1.8322E+01(S)
3	0.230 - 0.260	166746	2.7791E+03	1.7705E+01	2.5575E+01	2.1399E+01(S)
4	0.260 - 0.290	138679	2.3113E+03	2.1271E+01	2.9516E+01	2.5168E+01(S)
5	0.290 - 0.320	109939	1.8323E+03	2.3399E+01	3.1438E+01	2.7221E+01(S)
6	0.320 - 0.350	86143	1.4357E+03	2.4633E+01	3.2231E+01	2.8262E+01(S)
7	0.350 - 0.380	73747	1.2291E+03	2.7593E+01	3.5314E+01	3.1295E+01(S)
8	0.380 - 0.410	69357	1.1559E+03	3.3211E+01	4.1715E+01	3.7302E+01(S)
9	0.410 - 0.440	62073	1.0346E+03	3.7334E+01	4.6143E+01	4.1583E+01(S)
10	0.440 - 0.470	37702	6.2837E+02	2.8027E+01	3.4159E+01	3.0992E+01(S)
11	0.470 - 0.500	23237	3.8728E+02	2.1053E+01	2.5348E+01	2.3134E+01(S)
12	0.500 - 0.530	17318	2.8863E+02	1.8891E+01	2.2499E+01	2.0643E+01(NS)
13	0.530 - 0.560	11722	1.9537E+02	1.5229E+01	1.7964E+01	1.6559E+01(NS)
14	0.560 - 0.590	8781	1.4635E+02	1.3457E+01	1.5738E+01	1.4568E+01(NS)
15	0.590 - 0.620	6621	1.1035E+02	1.1867E+01	1.3770E+01	1.2795E+01(NS)

\*\*RANGE= 2 SUBTOTAL: MIN ACCUM VOL/S = 319.603  
 MAX ACCUM VOL/S = 412.054  
 AVE ACCUM VOL/S = 363.657

\*\*\* RANGE = 3 \*\*\*

CH#	DIAM.(MICR)	#COUNTS	#CNTS/SEC	MIN VOL/S	MAX VOL/S	AVE VOL/S
1	0.120 - 0.126	36712	6.1187E+02	5.5360E-01	6.4087E-01	5.9617E-01(S)
2	0.126 - 0.132	40644	6.7740E+02	7.0950E-01	8.1577E-01	7.6140E-01(S)
3	0.132 - 0.138	35926	5.9877E+02	7.2107E-01	8.2394E-01	7.7136E-01(S)
4	0.138 - 0.144	39427	6.5712E+02	9.0423E-01	1.0274E+00	9.6449E-01(S)
5	0.144 - 0.150	39295	6.5492E+02	1.0239E+00	1.1573E+00	1.0893E+00(S)
6	0.150 - 0.156	37943	6.3238E+02	1.1175E+00	1.2570E+00	1.1859E+00(S)
7	0.156 - 0.162	37502	6.2503E+02	1.2424E+00	1.3914E+00	1.3155E+00(S)
8	0.162 - 0.168	39570	6.5950E+02	1.4681E+00	1.6373E+00	1.5512E+00(S)
9	0.168 - 0.174	37288	6.2147E+02	1.5429E+00	1.7142E+00	1.6271E+00(S)
10	0.174 - 0.180	37480	6.2467E+02	1.7230E+00	1.9075E+00	1.8137E+00(S)
11	0.180 - 0.186	36281	6.0468E+02	1.8465E+00	2.0373E+00	1.9403E+00(S)
12	0.186 - 0.192	46007	7.6678E+02	2.5835E+00	2.8417E+00	2.7105E+00(S)

13	0.192 - 0.198	34203	5.7005E+02	2.1126E+00	2.3169E+00	2.2132E+00(S)
14	0.198 - 0.204	38342	6.3903E+02	2.5973E+00	2.8406E+00	2.7171E+00(PS)
15	0.204 - 0.210	36434	6.0723E+02	2.6993E+00	2.9445E+00	2.8201E+00(NS)

\*\*RANGE= 3 SUBTOTAL: MIN ACCUM VOL/S = 22.845  
 MAX ACCUM VOL/S = 25.354  
 AVE ACCUM VOL/S = 24.077

TOTAL 4 RANGES .. MIN ACCUM VOL/S = 527.931  
 MAX ACCUM VOL/S = 746.792  
 AVE ACCUM VOL/S = 630.063

# COMPARISON OF FLAME PHOTOMETER AND LAS-X DATA

Comparisons of flame photometer voltage and LAS-X total volume data for the four experiments are shown in Tables 3 and 4.

TABLE 3. FLAME PHOTOMETER AND PARTICLE VOLUME DATA

NaCl solution concentration	Voltage	Volume	Count mean diameter
Experiment 1			
1.0E-2	2.37	2976	0.16
1.0E-1	2.74	10898	0.17
1.E0-0	2.98	20576	0.20
1.0E-0	3.06	25300	0.22
Experiment 2			
1.0E-2	2.27	500	0.16
1.0E-1	2.72	2376	0.16
1.0E-0	2.97	5876	0.17
1.0E-0	3.07	10283	0.18

TABLE 4. FLAME PHOTOMETER VOLTAGE AND VOLUME DATA

Observation number	Voltage	Total volume	Count mean diameter
Experiment 3			
1	3.11	10208	0.182
2	3.12	9524	0.184
3	3.02	6108	0.182
4	2.81	3365	0.179
5	2.65	1783	0.178
6	2.45	933	0.176
7	2.19	499	0.176
8	1.95	249	0.173
9	1.79	136	0.174
10	1.49	80	0.172
11	1.31	47	0.170
12	1.08	122	0.169
13	0.92	27	0.168
14	0.69	21	0.165
15	0.51	18	0.165

TABLE 4. FLAME PHOTOMETER VOLTAGE AND VOLUME DATA (Cont'd)

Observation number	Voltage	Total volume	Count mean diameter
16	0.29	16	0.164
17	0.18	14	0.166
18	0.08	14	0.162
19	0.05	14	0.164
Experiment 4			
1	3.15	12973	0.189
2	3.05	7616	0.183
3	2.88	4158	0.178
4	2.67	2278	0.177
5	2.45	1127	0.176
6	2.23	555	0.174
7	2.00	232	0.175
8	1.69	132	0.173
9	1.50	60	0.172
10	1.38	38	0.171
11	1.10	23	0.169
12	0.84	16	0.167
13	0.58	14	0.163
14	0.39	12	0.162
15	0.24	11	0.164
16	0.16	11	0.163
17	0.07	11	0.161
18	0.04	11	0.163

Changes in voltage between experiments are within expected variability in reading voltages. The relationship between total aerosol volume (calculated from LAS-X data) and flame photometer voltage is shown in Figures 3 and 4. In each case the logarithm of the calculated aerosol volume and flame photometer voltage are linearly related. The coefficients of determination and regression (Table 5) for each linear regression are calculated by:

$$\text{Voltage} = a \log (\text{volume}) + b$$

where a and b are constants.

The relationship between flame photometer voltage and the logarithm of NaCl concentration when concentration was varied by changing NaCl solution strength is shown in Figure 3. The LAS-X, however, does not respond to particles less than about 0.1  $\mu\text{m}$  dia. Solution strengths of less than  $1.0\text{E}-3$  of the 5% solution cannot be used because the resulting aerosols are composed primarily of particles with diameters  $<0.12 \mu\text{m}$ . Comparison of the CMD for Experiments 1 and 2 indicates that the 20:1 dilution was inadequate in preventing coincidence [1]. (When coincidence occurs, the CMD of the aerosol is measured as greater than the true value and the particle count is too low [2].) Further dilution (from about 20:1 to 100:1) resulted in smaller CMD for Experiment 2 than Experiment 1. The progression of CMD in Experiment 2, however, may not be valid because of the particles outside the LAS-X range.

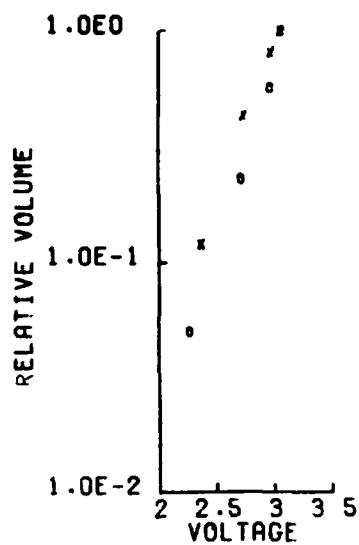


Figure 3. Graph of normalized aerosol volume and flame photometer voltage: Experiments 1 and 2.

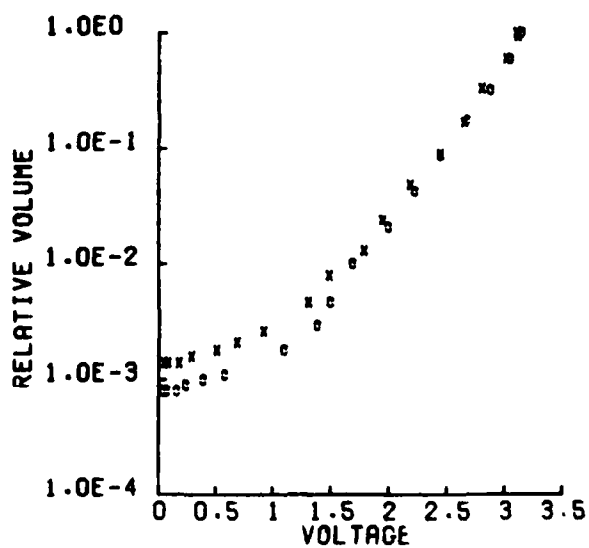


Figure 4. Graph of normalized aerosol volume and flame photometer voltage: Experiments 3 and 4.

TABLE 5. COEFFICIENTS OF DETERMINATION AND REGRESSION

Experiment	N	r	P	a	b
1	4	0.99	<0.01	0.74	-0.21
2	4	1.00	<0.01	0.62	0.61
3	19	0.95	<0.01	1.03	-0.76
4	18	0.95	<0.01	0.98	0.65

The relationship between NaCl concentration and flame photometer voltage when NaCl concentration is varied by diluting an aerosol generated by only one NaCl solution (5%) is shown in Figure 4. At lower concentrations there is a suggestion of curvature in the graph, indicating that voltage and the logarithm of volume may not be linearly related below 0.5 V or  $1.0 \times 10^{-3}$  relative volume. Count mean diameter decreases from about 0.19 to 0.16 over the course of the experiments (2 - 3 h) indicating that larger particles were being lost from the aerosol due to sedimentation, contrary to the assumption stated in a previous section.

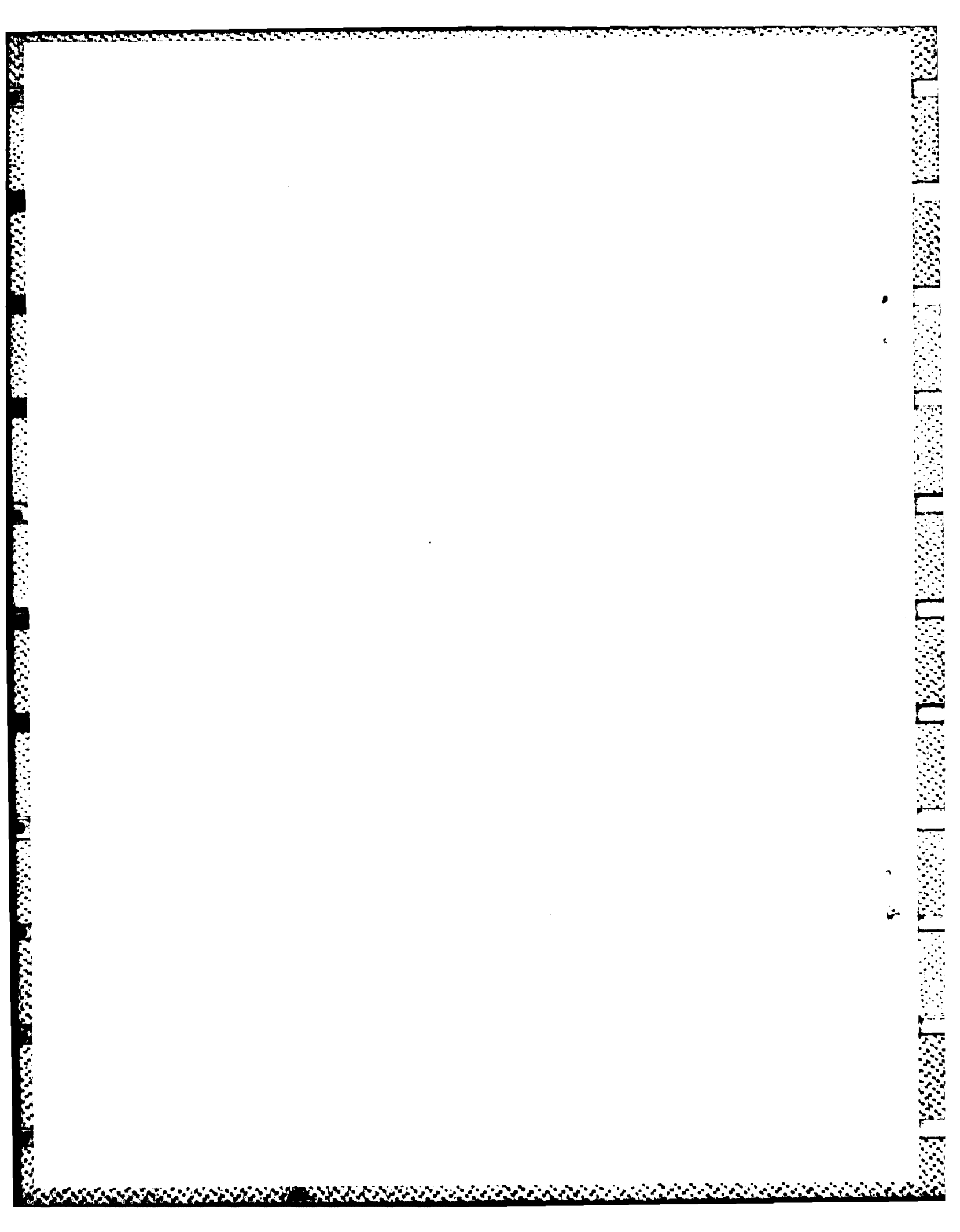
#### CONCLUSIONS

The relationship between the logarithm of particle volume calculated from LAS-X data and photometer voltage is linear over 3 - 4 decades in NaCl concentration. The linear relationship holds both when NaCl concentration is varied by varying NaCl solution strength and by diluting an aerosol generated from a single solution strength. The linear relationship when solution strength is varied indicates that the flame photometer is not sensitive to particle size in the range of data collected in Experiments 1 and 2.

Although calibration of the flame photometer by LAS-X total volume data is feasible, there is little advantage to this method over serial dilution, because only part of the flame photometer range is covered by the total particle volume data.

#### REFERENCES

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